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Eliminating stroop effects with post-hypnotic instructions: Brain mechanisms inferred from EEG

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ABSTRACT

The classic Stroop task demonstrates the persistent and automatic effects of the meaning of color words that are very hard to inhibit when the task is to name the word color. Post-hypnotic instructions may enable highly-hypnotizable participants to inhibit the automatic access to word meaning. Here we compared the consequences of hypnosis alone and hypnosis with post-hypnotic instructions on the Stroop effect and its facilitation and inhibition components. Importantly, we studied the mechanisms of the hypnosis effects at the neural level by analyzing EEG frequencies. Highly hypnotizable participants performed the Stroop task in a counterbalanced design following (1) post-hypnotic suggestions that words had lost their meaning, (2) after hypnosis alone, and (3) in a control condition without hypnosis. The overall Stroop effect and both its facilitation and interference components, were not significant after the post-hypnotic suggestion but in both other conditions. Hypnosis alone neither affected the Stroop effect nor – in contrast to some previous reports and claims – overall performance. EEG recorded during the Stroop task showed a significant increase in both frontal theta and frontal beta power when participants were under the impact of post-hypnotic suggestions, in comparison to the two other sessions. Together, these findings indicate that post-hypnotic suggestions – but not hypnosis alone - are powerful tools for eliciting top down processes. Our EEG findings could be interpreted as clue that this is due to the investment of additional cognitive control.

1. Introduction

Executive functions are employed when habitual behavior is inappropriate or insufficient to reach a goal at hand (Diamond, 2013). Although there is no consensus about the unity (Alvarez and Emory, 2006; Niendam et al., 2012) or diversity of executive functions and their constituents (Baddeley, 2003; Miyake et al., 2000), the most commonly suggested functions are inhibition, updating, and shifting (cf. Miyake et al., 2000). Egner and Raz (2007) proposed to employ post-hypnotic suggestions as a tool to investigate executive functions. Indeed, post-hypnotic suggestions have been successfully employed to diminish interference due to problems in inhibition, that is, in withholding or suppressing habitual responses. A special challenge to the inhibition function of executive control is the Stroop task (Miyake et al., 2000; Stroop, 1935). In this task, color names are printed in color. Participants respond to the print color by naming or pressing an appropriate key. Responses are usually slower and more error prone if color name and print color are incongruent, for example, *red* written in blue, than when they are congruent, for example, *red* written in red. The incongruency effect in this task is very persistent and robust against practice or conscious strategies (Macleod, 1991) and is often considered as a paragon of the impossibility to inhibit the meaning of attended written words (e.g., Macleod, 1991). By comparison with a neutral condition, the Stroop effect can be decomposed into an interference component (incongruent minus neutral) and a facilitation component (neutral minus congruent).

Within the framework of the Stroop model by Cohen and colleagues (Cohen and Huston, 1994; Cohen et al., 1990), there are two processing pathways for stimuli in the Stroop task, color naming and word meaning. The prepotent activation of word meaning is reflected by the strong weights of the word meaning pathway. Task instructions that ask for color naming but not word naming - the "task demand units" - sensitize the units of the color naming pathway and simultaneously desensitize the units for the word meaning pathway. This process, however, causes more cognitive demands in incongruent trials than in congruent or neutral trials. Based on the conflict monitoring model (Botnivick et al., 2001) top-down control or cognitive control is activated whenever conflict (at the response unit level) is detected by

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a conflict monitoring subsystem. The anterior cingulate cortex (ACC) has been considered to be a brain area majorly involved in conflict monitoring (Botvinick et al., 2001). Specifically, whenever a color naming conflicts with word meaning in the Stroop task, the ACC would signal conflict to recruit higher cognitive control processes, temporarily sensitizing the color naming pathway and desensitizing the word meaning pathway.

Two main approaches have been used to influence the Stroop effect by means of hypnosis. Most frequently, the task is preceded by a period of hypnosis including a post-hypnotic instruction about a strategy for dealing with the words. Strategies viable for non-hypnotized participants can be applied by both non-hypnotized and hypnotized participants, for example, not to attend to the words (e.g., Sheehan et al., 1988). However, such strategies have shown little effect on Stroop interference.

Other studies used strategies that are more beneficial for hypnotized than for non-hypnotized participants – even though there may be some benefit for the latter as well (Augustinova and Ferrand, 2012; Raz et al., 2006). For example, Raz et al. (2002, 2005, 2007) aimed at hampering the ability to read by suggesting during hypnosis that the words would belong to a foreign (unknown) language and hence were meaningless. In these studies, and also in others, using such, the Stroop effect was reduced by hypnosis but still significantly present. Only in the study by Raz et al. (2002, 2003), the Stroop effect disappeared: However, please note that in the study of Raz et al. (2003) the post-hypnotic session was always the second session, confounding conditions with order of testing.

After hypnosis - without introduction of any post-hypnotic suggestions for enhancement of Stroop performance - Sheehan et al. (1988) found increased mean RTs in Stroop task performance, although the Stroop effect itself was not reported. Nevertheless, the global increase in mean RTs after hypnosis was associated with a lack of self-produced strategies for surmounting interference (Egner and Raz, 2007). On the other hand, since hypnosis has been demonstrated to be effective in reducing anxiety (e.g., Olmsted et al., 1982), anxiety levels may be reduced after hypnosis. Therefore, it is reasonable, that diminishing their anxiety level, participants may more readily utilize self-produced strategies for overcoming interference. In line with this suggestion, Egner et al. (2005) implemented a variation of the Stroop task with two color words and two colors; however, they found no interaction between hypnosis (alone) and congruency conditions.

A further question is the source of the performance enhancement induced by post-hypnotic instructions given prior to the Stroop task. Some post-hypnotic suggestions aimed to prevent perceiving word meaning (for review see Lifshitz et al., 2013); hence, in this case cognitive control over any Stroop-induced conflicts may not have been involved at all. In addition, at least some previous studies (Augustinova and Ferrand, 2012; Raz et al., 2006) have shown that suggestions were to some extent efficacious even when they were presented outside of hypnosis. This could indicate that post-hypnotic suggestions merely implement the introduced strategy more implicitly and therefore more effectively.

To address the question of the mechanisms underlying post-hypnotic suggestion effects on Stroop task performance, we employed task-related EEG recordings in the present study, focusing on the theta (4–8 Hz) and beta (12–28 Hz) frequency bands. Changes in power in these frequency bands have taken to indicate variations in cognitive load and executive functions. With respect to theta power, Nigbur et al. (2011) suggested that its increase may serve as a marker of higher cognitive load and greater usage of executive functions. In line with this suggestion, Sauseng et al. (2007) revealed that frontal-midline theta power positively related to the level of task difficulty and Garavan et al. (2002), showed that higher frontal-midline theta activation would precede correct inhibition. Furthermore, increases in beta power and especially frontal beta power have been related to selective attention and cognitive control (Clayton et al., 2015; Coelli, Sclocco et al., 2015; Stoll et al., 2016). Both beta and theta power were used in the current study to shed light on the changes in usage of executive functions during task completion.

In addition to power, EEG coherence was analyzed for assessing cognitive and memory load. In the study by Sauseng et al. (2005), theta coherence of frontoparietal regions was interpreted to increase with task difficulty. However, the tasks in that study were qualitatively different, one calling for imagination and the other for recognition. Sauseng et al. (2007) suggested that theta power connectivity would be modulated by memory-related executive demands and independently of task difficulty. Egner et al. (2005) suggested that hypnosis results in a dissociation of conflict monitoring and cognitive control processes; although based on gamma-band coherence, which we will not conduct here, it is an interesting suggestion that we will follow up with respect to the coherence in theta and beta bands.

All region theta power in resting-state EEG is a commonly used marker for assessing state of consciousness (Graffin et al., 1995), and an increase of theta power during hypnosis induction have been found by many previous studies (Jensen et al., 2015, 2013; Sabourin et al., 1990; Williams and Gruzelier, 2001; for review, Jensen et al., 2015), besides, the study by Graffin et al. (1995) found a decrease in theta power in highly susceptible participants after hypnotic induction.

In the current Study, resting-state EEG was used to assess the state of consciousness during hypnosis induction, and task-related EEG was used for detecting the source of expected performance changes during the Stroop task.

As a first aim of the present study, we wanted to increase the efficiency of post-hypnotic instructions to eliminate Stroop effects. Raz and colleagues have repeatedly shown that the Stroop effect can be greatly diminished by a post-hypnotic instruction that script has lost its meaning; for example, in Raz et al. (2007) the Stroop effect was a mere 16 ms as compared to 118 ms in a no-hypnosis control condition. In the present study, we utilized the instructions given already during hypnosis, prior to the post-hypnotic suggestions, aiming to improve the effects of the latter. Such a strategy cannot be applied to non-hypnotized participants and might, therefore, be considered as being optimal for hypnotized participants. For the post-hypnotic instructions, we mostly followed Raz and colleagues that words had lost their meaning. We not only expected to replicate the findings of Raz and colleagues of strongly attenuated Stroop effects but an even stronger reduction due to the enhancement of the post-hypnotic suggestions by the preceding modified hypnotic instructions.

Our second aim was to assess the consequences of hypnosis alone on the Stroop effects relative to a control condition. We expected to replicate the slowing of overall RTs by hypnosis (Sheehan et al., 1988) and to find an increase of the Stroop effect, because due to the relaxing and anxiolytic effects of hypnosis, participants would suffer from lack of self-generated strategies to counteract the automatic activation of word meaning.

Thirdly, we aimed at investigating the mechanisms underlying the (post-)hypnotic effects on Stroop performance, by using EEG data. We assumed that the effect of our post-hypnotic suggestions would be exerted by cognitive control, especially constant suppression of processing irrelevant information (word meaning). That means a new strategy would be set up by the post-hypnotic suggestion inducing an inhibition of the prepotent response to reading the color words. In that case, the meaning of the words would not be perceived anymore. These increased demands on executive control functions should show up in an increase of theta and beta power, especially in the frontal-midline. Alternatively, our post-hypnotic suggestions might affect early perceptual processes resulting in the inability to read and perceive words' meaning. In that case, executive functions would not be directly addressed and we would expect a decrease in theta and beta power.

Furthermore, in hypnosis alone condition theta and beta power would decrease and RTs should increase, if participant won't be able to use their executive functions properly. In contrast, theta and beta